White Paper

Next-generation SONET for Cable MSOs:

Technical Overview

NORTEL NETWORKS™

Next-generation SONET/SDH

MSOs have several technology choices available to prepare them for GbE-based service delivery and the inevitable growth in digital transport bandwidth. This white paper provides an overview of Next-
generation SONET digital transport technology choices available to Cable Multiple System Operators (MSOs).

SONET standards were developed to provide robust, point-to-point, TDM-based signal transport across short, medium, long, and ultra long haul optical networks. SONET standards are hierarchal in nature and were predominantly designed for the transport of TDM-based voice signals. The table below outlines the bit rates of hierarchal SONET-based TDM payloads.

Bit rate	ANSI Asynch	SONET	
	Name	Tributary	Transport
40 Gbps	-	-	STS / OC-768
10 Gbps	-	-	STS / OC-192
2.5 Gbps	-	-	STS / OC-48
622 Mbps	-	-	STS / OC-12
155 Mbps	-	-	STS / OC-3
51 Mbps	-	-	STS / OC-1
45 Mbps	DS3 / T3	STS-1 SPE	-
1.5 Mbps	DS1 / T1	VT-1.5	-
64 kbps	DS0	-	-

Table 1: *SONET-based TDM payloads*

The line side optical bit rate of SONET equipment has continued to expand to meet growing voice transport requirements. Over the years, the line side optical bit rate of SONET equipment has grown from 155 Mbps to 622 Mbps to 2.5 Gbps to 10 Gbps. 40 Gbps SONET equipment is now emerging. Traditionally, OC-192 (10 Gbps)-based SONET transport was predominantly used in long haul applications in an effort to pack as many TDM channels onto a single optical carrier. Due to the reduction in the cost of OC-192 systems, this technology is now becoming cost-effective for metropolitan area applications as a means to expand metro area digital transport network bandwidth.

As SONET line rates have continued to grow, bandwidth and protocol flexibility of most SONET equipment has failed to keep pace. This is becoming increasingly important in metropolitan area transport networks where many different non-SONET data protocols and services now need to be supported. In addition, it is now widely noted that data traffic has overtaken TDM voice traffic on today's digital transport networks.

To satisfy the need to support traditional TDM applications as well as emerging non-SONET data protocols such as GbE and Fibre Channel, extensive "next-generation" standards development is and has been taking place. The goals are to accomplish the following:

- Provide SONET/SDH-compliant MAN and WAN transport of native, non-SONET protocols such as GbE and Fibre Channel
- Bring interface and protocol flexibility to SONET/SDH transport equipment
- Greatly improve service granularity, density, flexibility, and bandwidth use/efficiency for data-centric applications
- Drive intelligence into the SONET/SDH transport layer
- Continue to provide native delivery of traditional TDM payloads
- Deliver more profitable services by leveraging today's installed SONET infrastructure

Next-generation SONET/SDH solutions involve the implementation of several key, standards-based technologies onto SONET/SDH-based transport equipment. These standards include:

- ITU-T G.7041 Generic Framing Procedure (GFP)
- ITU-T G.707/783 Virtual Concatenation (VCAT)
- ITU-T G.7042 Link Capacity Adjustment Scheme (LCAS)
- IEEE 802.17 Resilient Packet Ring (RPR)

Generic Framing Procedure (GFP)

Generic Framing Procedure (GFP) is an emerging standard defined by ITU-T G.7041. GFP is a generic Layer 1 data encapsulation mechanism designed to accept and transport multiple native data protocols over metro and wide area digital transport networks. It has been designed to stop the proliferation of SONET mapping protocols (such as POS, x86

LAPS, and proprietary methods) for packet data services. GFP is deterministic with low overhead providing a robust, high integrity, flexible mapping method for data protocols, such as GbE, into traditional digital transport network payloads.

A common attribute of many widely used, high-speed data protocols is their reliance on 8B/10B physical layer coding. 8B/10B coding involves the conversion of 8 bit bytes into 10 bit codewords to ensure high transition density and DC balance (i.e. no long strings of 1's or 0's) for clock recovery circuits on the receiving end.

Two types of GFP-based mapping have currently been defined. These include "transparent" (GFP-T) and "framed" (GFP-F). Each provides a unique set of advantages over the other, depending on the application. The current GFP standard provides a clean mapping mechanism for emerging 8B/10B data protocols, specifically GbE, Fibre Channel, ESCON, and FICON. Additional proposals are being considered to extend GFP-T for the support of DVB-ASI and Fast Ethernet (100bT).

Transparent GFP (GFP-T)

Transparent GFP involves the mapping of the complete client signal into fixed length GFP frames, regardless of the information content of the signal. It is intended for low latency transmission of client data signals where the inter-frame gaps contain important client specific data, such as signaling information or flow control characters (e.g. Fibre Channel and ESCON). If a significant amount of the bandwidth in the client signal contains needless idles (e.g. GbE inter-frame gap, preamble, start of frame delimiter), these idles are transported in a transparent fashion resulting in the consumption of unnecessary transport network bandwidth. Finally, transparent GFP requires only minimal client signal awareness, thereby allowing a single hardware design to transparently transport multiple protocols based on 8B/10B coding.

Frame-based GFP (GFP-F)

Frame-based GFP involves the mapping of client data frames only into GFP frames. Inter-frame bytes of the client signal are not mapped into GFP frames. Therefore, transport network bandwidth is better utilized, especially on lightly loaded client signals, because meaningless idles and inter-frame gaps are not transported across the network. While GbE, Fibre Channel, ESCON, and FICON share common 8B/10B physical layer coding, they do not share common frame delineation and packet formats. As a result, a protocol specific physical coding sublayer and MAC are required to extract and transport each protocol via frame-based GFP encapsulation. Therefore, different hardware designs are required to transport each of these protocols using frame-based GFP.

Figure 1 provides a pictorial view of both frame-based and transparent GFP encapsulation.

In conclusion, GFP-T and GFP-F offer a differentiating set of capabilities and permit a diverse range of data service offerings. GFP-T is ideal for Storage

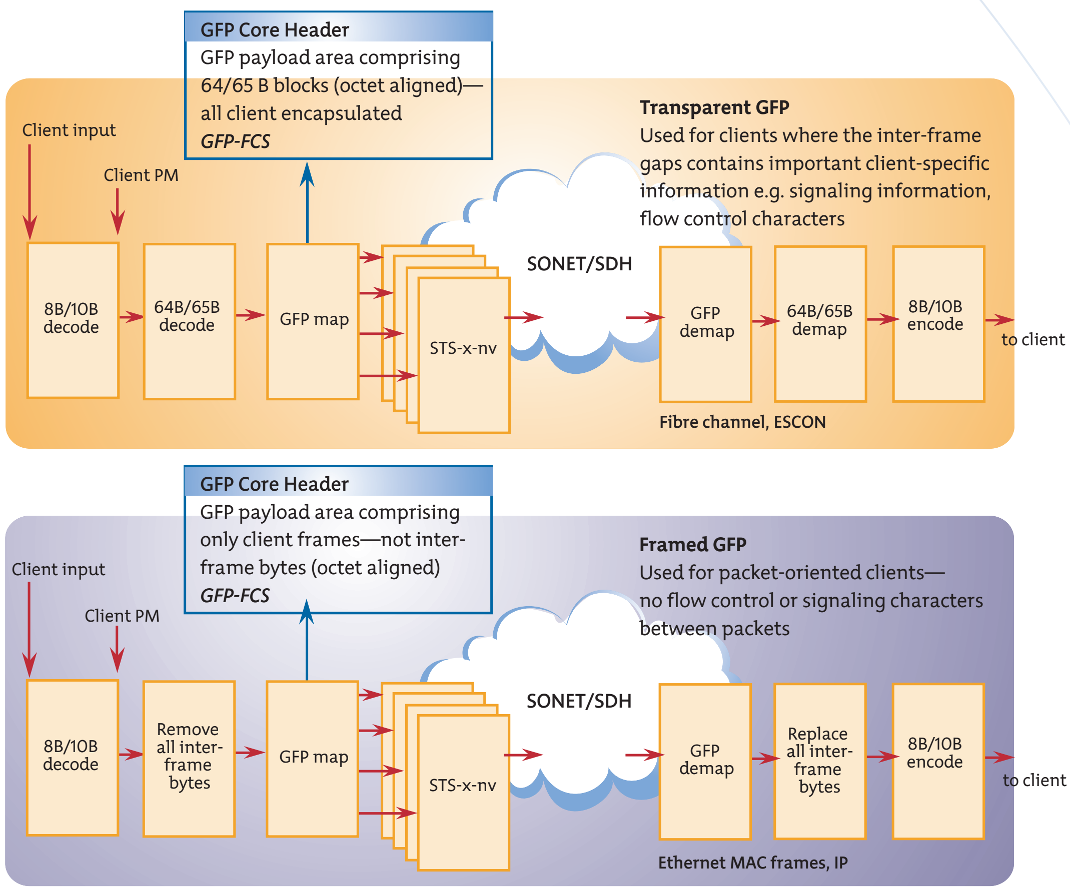


Figure 1. *Transparent GFP and Framed GFP*

Area Network (SAN) applications while GFP-F is better suited to Ethernet applications. The following table compares these GFP framing formats.

Virtual Concatenation (VCAT)

Virtual Concatenation (VCAT) is an existing standard defined by ITU-T G.707/G.783 and ANSI T.105. VCAT is not a new concept in principle. It was originally designed to extend the utility of the SONET/SDH transport layer although it hasn't been adopted to date as a mainstream networking technology. VCAT enables more efficient support of packet-based data services through the "right" sizing of SONET/SDH channels and bandwidth.

SONET/SDH transport structures, including contiguous concatenation (i.e. OC-3c/12c/48c/192c), are optimized for traditional TDM transport applications and are rigid in nature. VCAT provides a highly granular, flexible, and efficient method of provisioning traditional SONET/SDH transport bandwidth for data-oriented service transport. Specifically, VCAT allows for the grouping of non-consecutive SONET/SDH synchronous payload envelopes (SPEs) to create "virtual" concatenation bandwidth groups. With VCAT, an arbitrary number (X) of virtual containers (STS-1/3c SPEs) are grouped together with the combined payload (STS-n-Xv) used to match the required bandwidth.

As an example, a wire speed GbE client signal (1,000 Mbps) can be mapped to a VCAT group of 21 STS-1s (21 x 51.8 Mbps = 1088 Mbps) resulting in a bandwidth efficiency of approximately 92 percent. Likewise, the same wire speed GbE client signal (1,000 Mbps) can be mapped to a VCAT group of 7 STS-3cs (7 x 155.4Mbps = 1088 Mbps) to achieve the same bandwidth efficiency of 92 percent. Conversely, if traditional contiguous concatenation is used for the same wire speed GbE client signal (1,000 Mbps), an OC-48c (2.488 Gbps) would be required, thereby wasting approximately 60 percent of the provisioned bandwidth. The following table shows how VCAT can provide substantially improved bandwidth efficiency as compared to traditional SONET/SDH contiguous concatenation approaches for various data protocols.

As displayed, VCAT results in improved SONET/SDH transport capacity efficiency as well as much finer SONET/SDH bandwidth granularity. VCAT combined with GFP enables SONET/SDH transport elements to more effectively transport data-centric protocols, such as GbE, in their native formats.

Supported characteristic	GFP-F	GFP-T
Transparency to 8B10B—frame control codes	no	yes
At full rate minimizes WAN bandwidth (removes IFG)	yes	no
Permits per-frame performance monitoring	yes	no
Permits sub-rate bandwidth (with frame granularity)	yes	no
Minimizes latency for delay-sensitive protocols	no	yes
Long distance for Ethernet (local 802.3x PAUSE)	yes	no
Optional error correction for error-sensitive protocols	no	yes
Permits sharing of transport pipe among multiple clients	yes	yes*

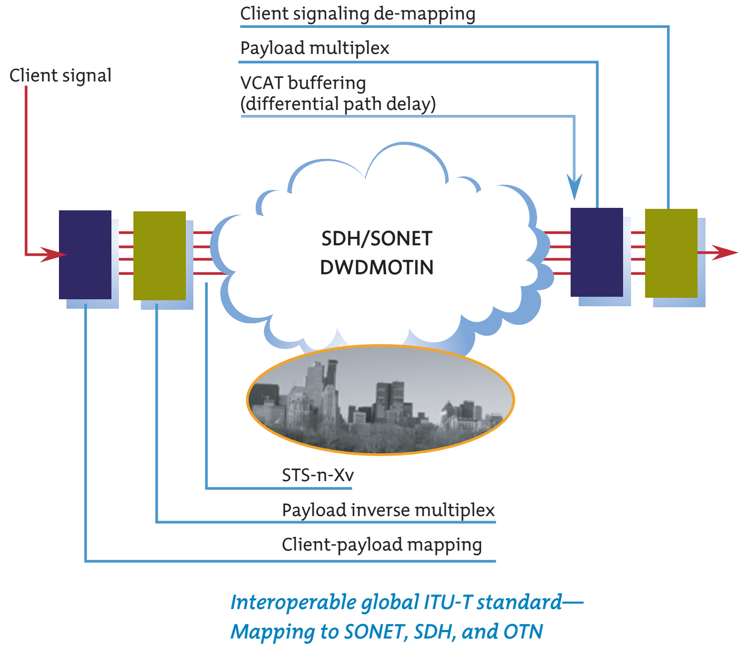
Table 2: *Characteristics of GFP-F and GFP-T*

Service protocol	Client rate	Contiguous concatenation		Virtual concatenation	
Fast Ethernet	100 Mbps	STS-3c	65%	STS-1-2v	98%
ESCON	160 Mbps	STS-12c	26%	STS-1-4v	78%
Fibre Channel	850 Mbps	STS-48c	34%	STS-3c-6v	92%
Gigabit Ethernet	1 Gbps	STS-48c	40%	STS-1-21v	92%
		STS-3c-7v	92%		
Fibre Channel 2	1.7 Gbps	STS-48c	68%	STS-3c-12v	92%

Table 3: *Comparison of Contiguous Concatenation and Virtual Concatenation*

Link Capacity Adjustment Scheme (LCAS)

Link Capacity Adjustment Scheme (LCAS) is an emerging SONET/SDH standard and is defined in ITU-T G.7042. As we have indicated, VCAT provides the ability to "right" size SONET/SDH channels and bandwidth resulting in more efficient support of packet-based data services. LCAS increases the flexibility of VCAT by allowing the dynamic reconfiguration of virtual concatenation groups.



Generic Framing Procedure

- Efficient network resource utilization
  - Low GFP overhead
  - No over-provisioning with VCAT
- End-to-end service framing, PM and SP OAM, demarc
- Layer 2 independent
  - Supports RPR, other Layer 2 protocols
- Enables network consolidation
  - Converges next-generation services with existing infrastructure investment

Virtual Concatenation

- Efficient network resource utilization
  - "Right-sized" SONET/SDH bandwidth channels
  - Reduction in over-provisioning
  - End-to-end proficiency for packet services
- TDM QoS, jitter performance
  - Deterministic QoS for all series
- Newsoft protection schemes
  - LCAS (ITU-TG.7042) allow dynamic reconfiguration of VCAT payloads
  - LCAS provides automatic signaling capability

Figure 2. *Features and advantages of GFP, VCAT, and LCAS*

LCAS eliminates the slow and inefficient provisioning process of classical SONET/
SDH networks and offers a means to incrementally enlarge or shrink the size of a SONET/SDH data pipe without affecting the transported data. LCAS is used to add or remove members (STS-1s or STS-3cs) of a VCAT group resulting in the "hitless" provisioning of more/less bandwidth over a live SONET/SDH VCAT circuit. LCAS uses a request/acknowledge mechanism that allows for the addition or removal of STS-1s/STS-3cs to/from a VCAT bandwidth group. Finally, the LCAS protocol works unidirectionally, enabling service providers to provide asymmetric bandwidth. This is particularly important for MSOs requiring asymmetric transport bandwidth as seen in VoD deployments where content is distributed from VoD servers to edge QAM devices.

Figure 2 exhibits the advantages of GFP, VCAT, and LCAS. To employ GFP, VCAT, and LCAS over an existing SONET/SDH network, only the terminals at the end points of the connection need be modified. This allows service providers to deploy GFP, VCAT, and LCAS in a simple manner by installing new tributary cards. Likewise, they can scale these implementations by adding more tributary cards to any other terminals in the network as required.

On a final note, GFP, VCAT, and LCAS have been added to the family of SONET standards to improve SONET protocol flexibility, bandwidth granularity, and efficiency. Nonetheless, these improvements do not change the circuit-based approach of SONET as the point-to-point nature of each data connection remains. Additionally, protection bandwidth continues to be reserved for every point-to-point connection and other nodes on the ring cannot claim unused bandwidth. Resilient Packet Ring technology addresses these concerns and is aimed at improving SONET/SDH network technology further.

Resilient Packet Ring (RPR)

Ethernet is a low-cost, ubiquitous Layer 2 transport protocol that dominates today's LAN environments. The main drawback of Ethernet is that it is a point-to-point, unprotected data transport protocol that lacks carrier-class attributes. A router or switch processes each data packet at every hop in an Ethernet-based network. This attribute can be time consuming in larger Ethernet networks, thereby resulting in jitter and latency performance that is typically inadequate for real time services such as voice and video.

Legacy SONET/SDH networks offer client access in the form of DS0, T1, DS3, OC-n, and in some cases, Ethernet. Today's SONET/SDH networks offer exceptional jitter and latency performance and provide loss-less packet transport because packet data is transported from source to destination without the need for QoS decision-making in between. In addition, SONET/SDH networks reserve spare bandwidth capacity and provide 50 msec protection switching in the case of equipment faults or fiber cuts.

Resilient Packet Ring (RPR) is an emerging Layer 2 protocol that is being defined by the IEEE 802.17 working group. RPR combines the low cost, efficiency, and simplicity of Ethernet with the high availability, reach, resiliency, and scalability of SONET transport technology. By combining the advantages of both SONET and Ethernet, RPR provides support for new, connectionless, packet-based services while also providing traditional carrier-class features such as low latency and jitter, QoS, resiliency, and path restoration.

The result is the best of both worlds—a resilient, packet-oriented, ring-based solution that provides virtual mesh data networking connectivity.

RPR—Ring Operation

Resilient Packet Rings are ring-based networks that are optimized for connectionless data transport. As displayed in *Figure 3,* RPR networks employ at least two counter-rotating physical rings used to connect all attached RPR network elements.

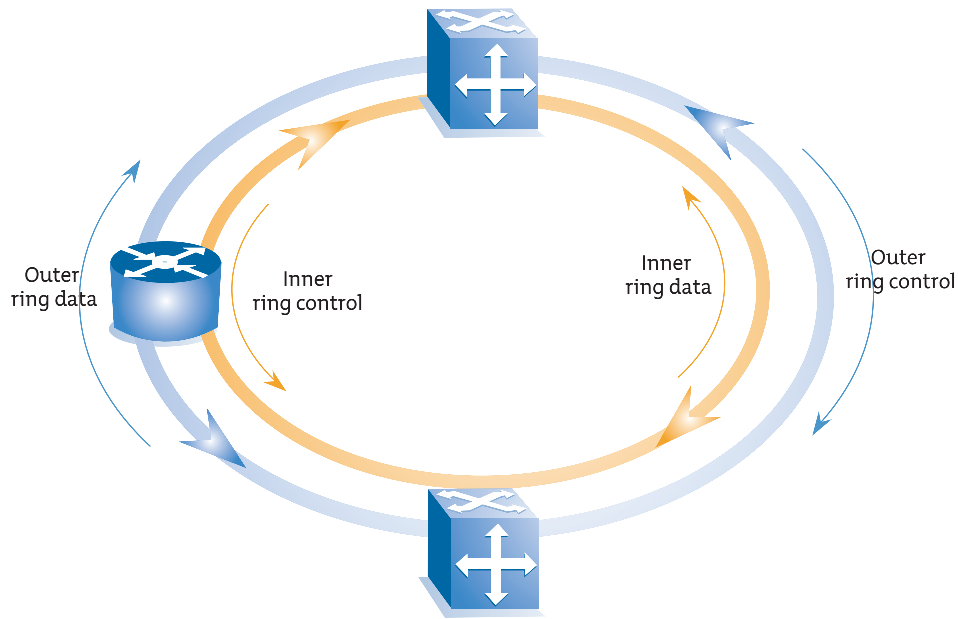


Figure 3. *Dual counter rotating rings of RPR technology*

Both physical rings are used to carry working traffic, thereby allowing bandwidth traditionally set aside for SONET protection to be utilized. This results in a doubling of available bandwidth capacity. For example, an OC-12 (622 Mbps) RPR ring provides 1.244 Gbps (2 x 622 Mbps) of usable bandwidth.

RPR networks use a topology discovery algorithm such that all attached nodes automatically learn the topology of the network. In the topology map, each element stores a primary and secondary path to every other element. Data is sent via the optimal path only—typically the shortest path unless a network failure condition exists. If a failure occurs, packets are automatically sent to the destination node via the secondary path within 50 msec. Additionally, destination nodes strip packets destined for them from the ring thereby resulting in bandwidth consumption only on the traversed segment. Therefore, the unused spans on the ring remain idle and are available to other stations and data streams. Spatial re-use is the term used to describe this property of RPR.

All attached nodes in an RPR ring share the available transport bandwidth without the need for provisioning circuits. The attached nodes automatically negotiate for access to ring bandwidth among themselves via a fairness control algorithm. Additionally, RPR provides express treatment of all marked packets, thereby offering QoS for mission-critical traffic. Unlike Ethernet networks, RPR has a transit path architecture that allows packets to quickly bypass intermediate nodes en-route to their destination. This feature allows RPR networks to provide low latency and jitter performance for time-sensitive services such as voice and video.

RPR Media Access Control (MAC)—details and features

The IEEE 802.17 working group is currently defining the RPR MAC protocol. As with all Layer 2 protocols, RPR defines a media access control (MAC) mechanism that defines the manner in which available bandwidth on the physical media can be utilized by transmitting stations. MAC protocols, including the RPR MAC, also define how stations should react to congestion or collisions on the physical media. Finally, the RPR MAC prioritizes and buffers packets, thereby providing regulated access to the media. *Figure 4* provides a high-level functional view of the RPR MAC.

As displayed, each RPR element contains two MACs to provide communication over the inner and outer RPR fiber rings. In a standard transaction, the host system sends control information, including topology, fairness, protection, and OAM statistics, as well as data information to the MAC control sublayer. The MAC control sublayer in turn sends RPR frames to the appropriate MAC for transmission over the physical layer.

Packets received on either MAC are only routed to the host client if a destination address match is encountered. All other packets are placed back on the physical ring media to transit toward other nodes on the ring. This "transit" function reduces packet delay significantly.

The RPR MAC offers four service classes to the host client. These include:

- **Reserved—**Unlike other services, the unused idle bandwidth for 'reserved' services is not available to other services, thereby making this service class similar to TDM circuits.
- **High Priority (Class A)—**This service provides Committed Information Rate (CIR) and guaranteed bandwidth for high priority traffic that is jitter and latency sensitive. Traffic in this class is not subject to the RPR bandwidth-sharing algorithm. Voice, video, and circuit emulation applications are ideal for this service class.
- **Medium Priority (Class B)—**This service is for CIR and other provisioned bandwidth applications requiring less stringent (but still bounded) jitter and latency requirements. Access to ring bandwidth is guaranteed for this service class as well. Business data applications are ideal for this service class.
- **Low Priority (Class C)—**This service provides best effort access to ring bandwidth. RPR nodes use a bandwidth-sharing algorithm to negotiate for a fair share of the ring capacity for traffic in this class. RPR ring bandwidth is dynamically distributed for

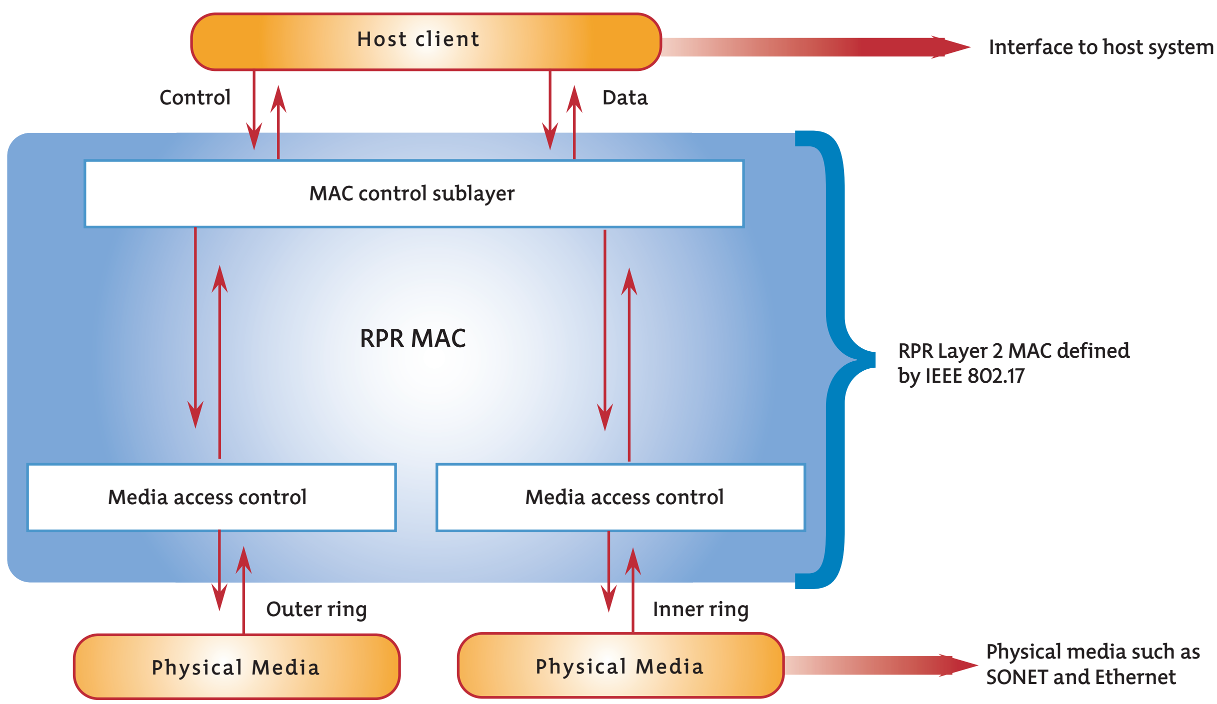


Figure 4. *High-level RPR MAC functional view*

traffic in this class. This service class is ideal for best effort, consumer Internet traffic.

The RPR MAC has several prime functional blocks that collectively allow it to offer many advantages over legacy Ethernet and SONET/SDH networks. These functional blocks include the MAC client interface, drop logic, transit path, bandwidth manager, protection, topology, and physical layer as described in *Figure 5.*

The purpose of each of the functional blocks is as follows:

- **MAC client interface—**This interface allows the host to transmit and receive data based on the service class. The RPR MAC client interface provides the ability to back pressure the host system, thereby ensuring that transmitted packets have ring bandwidth available.
- **Drop logic—**The RPR MAC inspects the destination address of all incoming packets to determine if the packet should be stripped from the ring or placed in the transit buffer for transmission to other nodes. The drop logic function performs the following functions:
  - Strips uni-cast packets from the ring and delivers them to the MAC client interface if a matching destination address to that of the station is observed
  - Copies multi-cast packets to the MAC client interface and places them in the transit path for transmission to other nodes
  - Places uni-cast packets in the transit buffer if their destination address does not match that of the station
  - Strips bandwidth notification packets and passes them to the bandwidth manager
  - Strips packets from the ring if they are corrupted or their time to live has run out
- **Transit path—**The transit path allows packets to quickly bypass intermediate RPR nodes as they travel to their destination. It contains a small high-priority and large low-priority buffer that can hold up to two data packets. Packets are stored here while waiting for the local host to complete its current transmission. The transit path is the key enabler of RPR's ability to deliver reliable, time-sensitive services.
- **Bandwidth manager—**The RPR MAC tracks the bandwidth usage for low priority packets and compares it to bandwidth notification messages from downstream nodes. The system decides how much bandwidth is available for low priority data and whether local host client back pressure should be applied. The bandwidth manager shapes and limits bandwidth for each traffic class and enforces prenegotiated bandwidth limits, as set by the RPR fairness algorithm, for low priority data. The bandwidth manager also arbitrates whether transiting packets from other nodes or traffic from the local host will be placed on the physical media.
- **Protection—**RPR provides a 50 msec protection mechanism for packet traffic. It uses packet steering as a default with the option for packet wrapping. With packet steering, all stations are notified of a network failure and transmitting stations choose the ring that avoids the failed span until they receive notification that the failure has been cleared. With packet wrapping, the nodes adjacent to the failure wrap traffic to the other fiber ring. Other nodes on the ring are notified and they eventually steer their packets away from the failure until notification that the failure has been cleared.

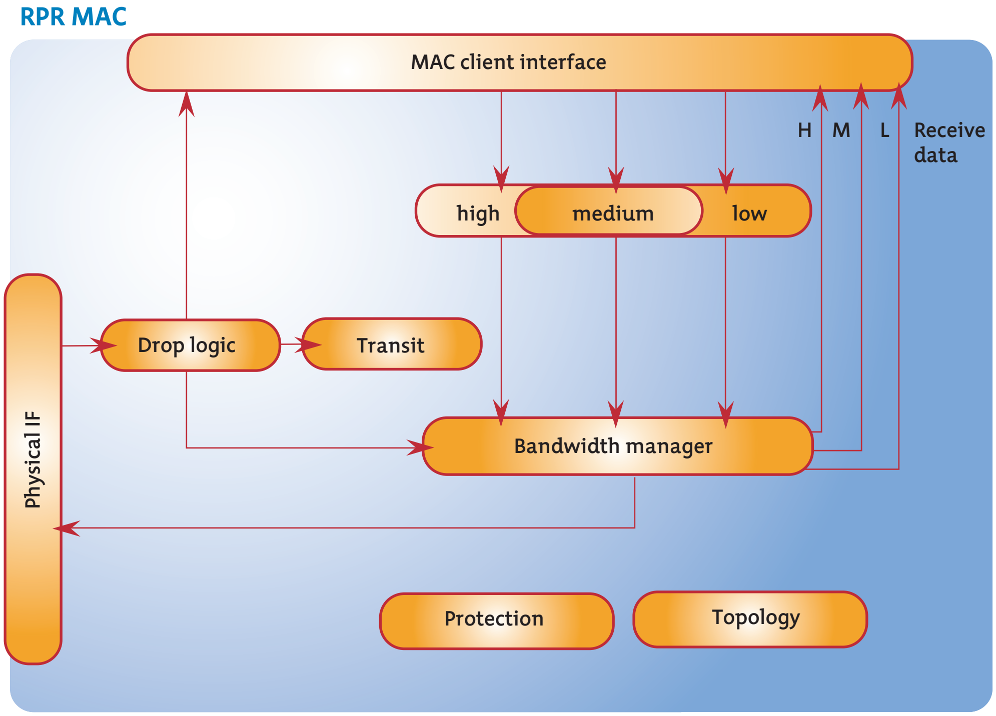


Figure 5. *Functional blocks of RPR MAC*

- **Topology—**The topology discovery algorithm of RPR allows attached nodes to automatically learn the topology of the network. Therefore, the host node can determine primary and secondary paths to all other attached nodes and thereby choose the path a packet will take (typically the shortest path is chosen). The topology map is updated at regular intervals and after protection events. This process allows nodes to be added or removed from an RPR ring without the requirement for a manual provisioning process.
- **Physical layer—**RPR uses existing physical layer solutions, including existing framers and optics. The IEEE802.17 working group is developing a reconciliation layer that will support PoS and GFP encapsulated SONET and Ethernet physical layers.

RPR performance benefits

Resilient Packet Ring technology offers multiple performance benefits, including:

- **Bandwidth efficiency—**Because RPR uses both working and protection bandwidth for live packet traffic, no bandwidth is wasted. Due to RPR's transit path architecture and its ability to use bandwidth only along the transversed segment while stripping uni-cast packets at their destination, "spatial reuse" of bandwidth is achieved. This results in further bandwidth multiplication because unused portions of ring bandwidth can simultaneously be used between other nodes. RPR also provides a highly efficient mechanism for transmitting multicast traffic. Unlike meshed topologies where many packet copies are sent over multiple paths, RPR nodes have the ability to receive a multicast packet as well as send it on to the next node in the ring. Therefore, only one copy of a multicast packet is sent around the ring.
- **Carrier-class packet service performance—**With RPR, each node has two paths to every other node and packet steering is used to automatically protect against fiber or equipment failures within 50msec. In addition, RPR provides exceptional latency and jitter performance for mission-critical applications such as Voice over IP.
- **QoS and fair access to ring bandwidth—**RPR provides multiple classes of service for packets on or entering the ring. New, differentiated packet services are easily accommodated over a common network by providing separate classes for latency/jitter sensitive traffic, committed information rate, and best effort traffic. The RPR fairness algorithm ensures that each node is given a guaranteed amount of bandwidth, thereby preventing any single node from being starved from access to ring bandwidth.
- **Ease of management—**RPR offers plug-and-play simplicity, negating the need for manual provisioning when nodes are added or removed from the ring. With automatic mechanisms for topology discovery and protection, RPR requires little or no operator management.
- **Scalability—**RPR networks provide high scalability by allowing over 64 nodes on a single ring. Nodes can be added or removed from a ring with topology discovery, bandwidth management, and protection algorithms automatically accounting for the change. Changes in bandwidth can be accomplished quickly without complex provisioning steps or truck rolls.

RPR implementations

Although RPR can be used to replace both SONET and Ethernet networks, it is and will be used in combination with both. For example, RPR is available on present day SONET/SDH transport equipment as well as on traditional IP/Ethernet routing equipment.

RPR and the physical layer

The IEEE 802.17 working group is not defining physical layers that are unique to the RPR Layer 2 MAC. Instead, the intent is to reference accepted and proven physical layers for use by RPR. Physical reconciliation sublayers are used to translate between a physical layer interface and the common, standardized RPR Layer 2 MAC interface. The standard currently defines such physical layer interfaces for both SONET and Ethernet physical layers.

For SONET/SDH physical interfaces, two reconciliation sublayers have been defined. The SONET/SDH reconciliation sublayer (SRS) defines an HDLC-like encapsulation for RPR frames that is similar to PoS encapsulation. The GFP reconciliation sublayer (GRS) defines an encapsulation method using Generic Framing Procedure.

For Ethernet, the GbE reconciliation sublayer (GERS) defines an interface between the common RPR Layer 2 MAC, and the GbE media independent interface (GMII). The 10 GbE reconciliation sublayer (XGERS) defines interfaces between the RPR MAC and the 10 GbE media independent interface (XGMII) and 10 GbE AUI interface (XAUI).

RPR on SONET/SDH equipment

On SONET/SDH optical network elements, RPR is implemented by integrating RPR-enabled Ethernet interface cards and packet switching capabilities to create an intelligent, distributed Layer 2 switch that uses SONET/SDH bandwidth as a virtual backplane between end points. *Figure 6* is an illustration of this approach.

Each RPR interface card is a highly intelligent Layer 2 Ethernet switch. RPR cards come in multiple port densities with various interfaces, such as 10/100 BASE-T, 10/100 BASE-FX, and GbE. They support standard Ethernet protocols such as IEEE-802.1Q and IEEE 802.1p.

RPR-enabled SONET/SDH networks allow all, or a portion of, a ring's total SONET bandwidth to be provisioned as a 'pool' and dynamically distributed between multiple RPR interface cards deployed throughout the ring. Each dynamic 'pool' of provisioned bandwidth is referred to as a virtual RPR ring as displayed in *Figure 7*. A single network can support multiple, independent, virtual RPR rings if required.

The key advantage of RPR-enabled SONET/SDH transport networks is the ability to dynamically distribute bandwidth for packet traffic while continuing to leverage the non-RPR portion of network bandwidth for TDM services. Therefore, TDM services can be supported in their traditional manner with no loss of performance as opposed to utilizing packet-based circuit emulation methods. As a result, service providers can use their currently installed SONET/SDH infrastructure to deliver new packet-based, managed Ethernet services complete with SLAs, while continuing to deliver legacy TDM services with no loss of performance.

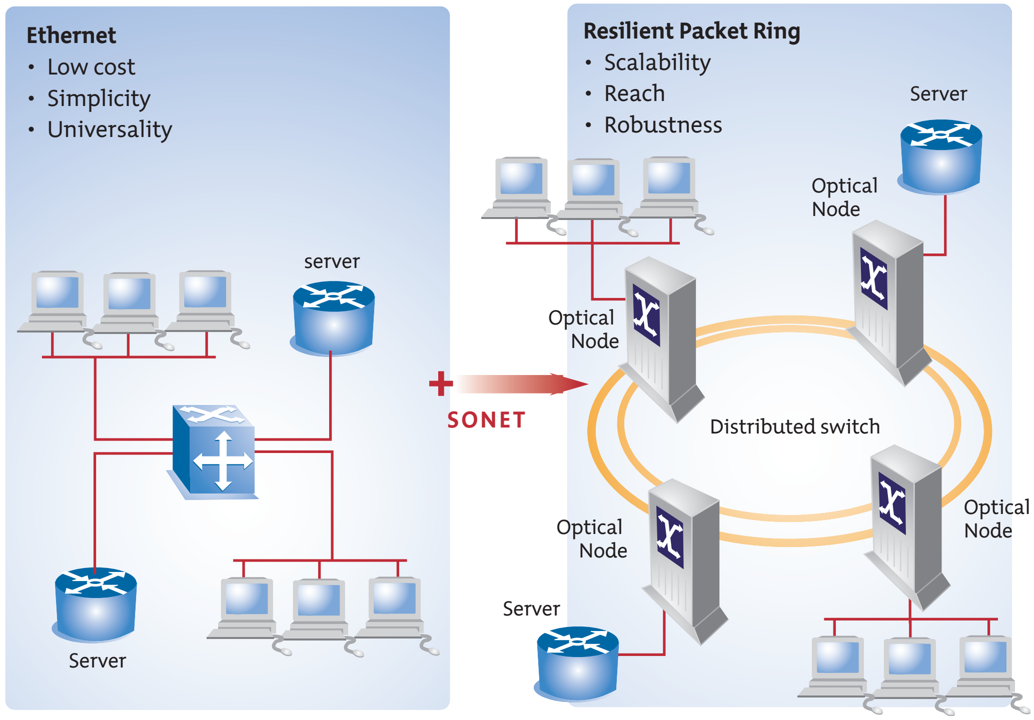


Figure 6. *RPR Implementation on SONET/SDH*

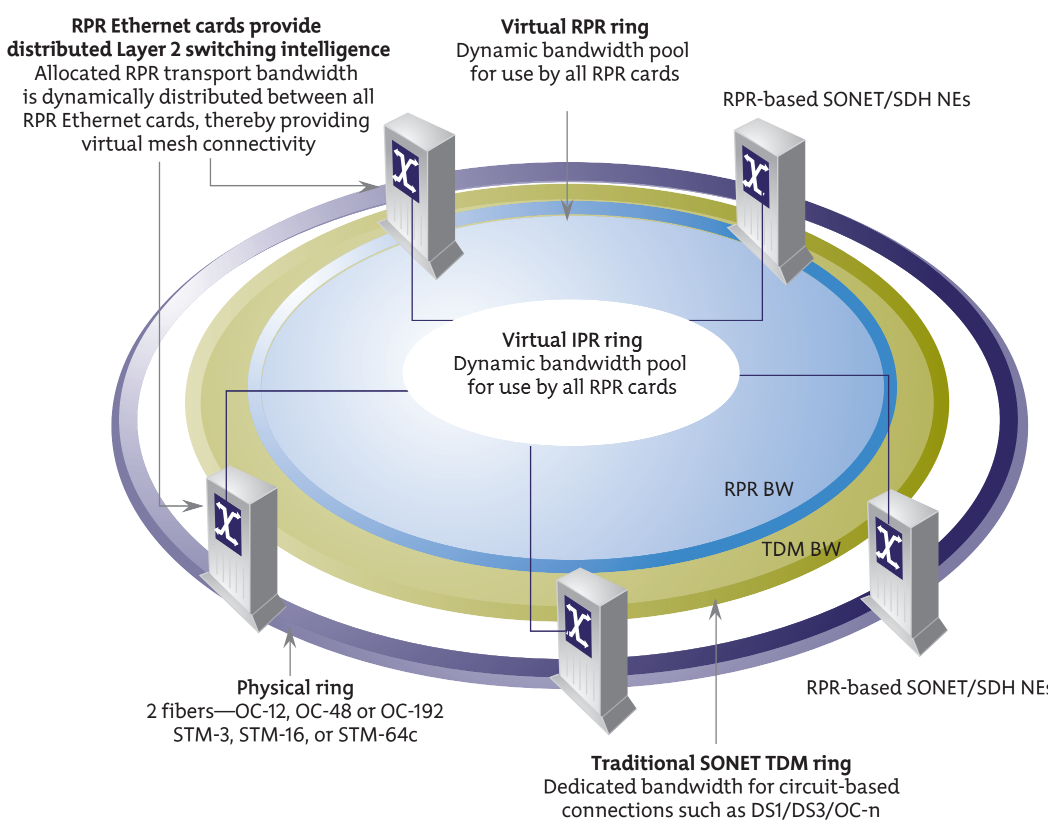


Figure 7. *TDM and RPR transport on common SONET/SDH network*

RPR on IP routing/Ethernet switching equipment

On many IP routing/Ethernet switching network elements, Ethernet is used as a client side interface and Packet over SONET (PoS) as a Layer 1 point-to-point WAN interface. Because RPR is supported on the SONET physical layer in a manner similar to PoS, it can be incorporated as a Layer 2 protocol into the WAN side of today's IP routed/ Ethernet switched networks to provide highly resilient, virtual mesh connectivity. This is displayed in *Figure 8*.

Additionally, RPR will facilitate the doubling of traditional PoS bandwidth. For example, an IP-routed OC-48c POS ring will have double the bandwidth capacity (from 2.5 Gbps to 5 Gbps) with RPR while continuing to provide 50 msec protection switching. Today, Layer 2 and Layer 3 network topology information is exchanged between these network elements on a continuing basis. In the case of a network fault, Layer 2 spanning tree protocol or Layer 3 protocols, such as BGP and OSPF, must "re-converge" to route traffic around the network fault. This process can, in many cases, take from several seconds to minutes to complete. Because RPR provides 50 msec protection switching, when installed as a Layer 2 WAN interconnect mechanism between IP routing equipment and/or Ethernet switches, network faults can be avoided without triggering traditional Layer 2 and Layer 3 reconvergence. With RPR, high layer protocols such BGP and OSPF are none the wiser that a fault has even occurred.

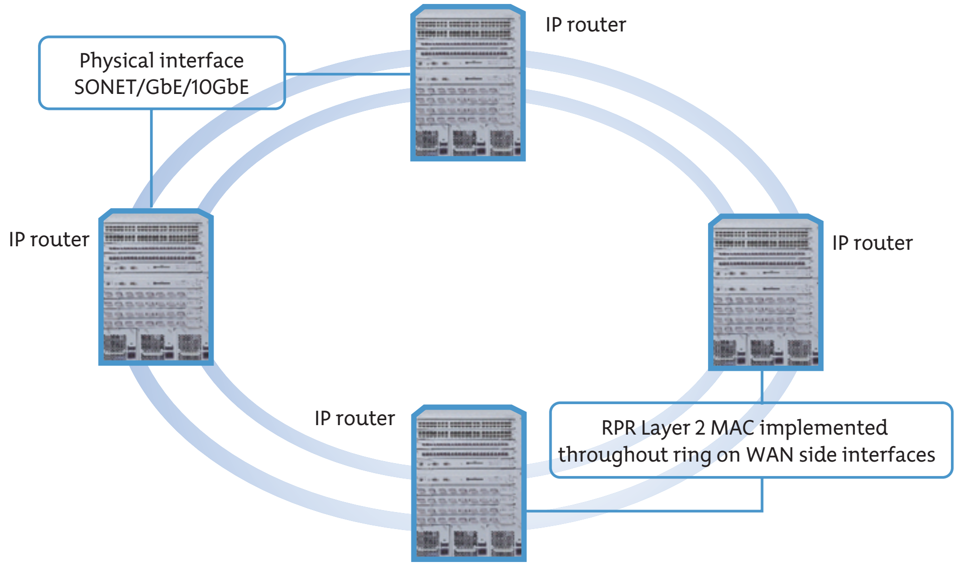


Figure 8. *RPR-enabled IP routed network*

In addition to increased resiliency, RPR employed on the WAN side of today's IP-routed/Ethernet-switched networks will assist in significantly improving both jitter and latency performance. This is due to RPR's shortest hop, transit-based architecture. With many of today's IP/Ethernet or PoS physical ring-based architectures, a router or switch fully processes each packet through the routing or switching engine in order to make a forwarding decision to the next device. This results in higher packet loss, jitter, and unnecessary latency when compared to RPR networks.

The outstanding resiliency, bandwidth efficiency, and jitter/delay performance of RPR, combined with its QoS attributes, make this technology especially important for MSOs wishing to use their installed base of IP routing/Ethernet switching equipment for the transport of mission-critical traffic such as VoIP. RPR is poised to become a dominant Layer 2 WAN interconnect mechanism for both core and aggregation IP-routed/Ethernet-switched devices within the MSO digital transport network.

Next-generation SONET wrap-up

As we have discussed, GFP, VCAT, and LCAS are a collection of new and existing standards designed to improve SONET/SDH protocol flexibility, bandwidth granularity, and efficiency. The table in *Table 4* lists the standards that describe these protocols.

It should be noted that these protocols do not change the point-to-point, circuit-based nature of traditional SONET/SDH networks. These protocols are all Layer 1-specific. GFP, in both of its forms, is a Layer 1 frame to SONET mapping protocol. It is not designed to replace RPR, which defines a new Layer 2 MAC protocol. In fact, RPR can use GFP as a Layer 1 mapping protocol and the IEEE 802.17 working group is currently developing a reconciliation layer to provide this functionality. The GFP-based point-to-point data transport approach and RPR ring-based packet data approach enable different, complimentary services as described by *Table 5*.

Finally, it is important to note that multiple pre-standard implementations of RPR solutions have been on the market for some time. Specific examples of these include Nortel Networks OPTera Packet Edge (OPE) and Cisco Systems Dynamic Packet Transport (DPT) solutions. However, the new RPR MAC as being defined by the IEEE 802.17 Working Group fosters greater interoperability across both silicon and system implementations. The availability of standard-based products will benefit end users by supporting a multi-vendor environment. The IEEE 802.17 Working Group was first formed in December 2001 and the first draft standard was published in August 2002.

Region	Standard	Description	Status
Global	G.7041	Defines GFP.	**Approved** 2001 version + '02 addendum/corrigendum
	G.707 (sect 11)	Defines VCAT. Also defines contiguous concatenation.	**Approved** 2000 version + '02 addendum/corrigendum
	G.783	Detailed equipment specifications (that include VCAT support requirements).	**Approved** 2000 version + addendums
	G.7042	Defines LCAS. Refers to G.707 and G.783 for VCAT function.	**Approved** 2001 version + '02 addendum/corrigendum
	G.709/G.798	Definition + equipment specification for VCAT of ODUk.	
	IEEE 802.17	Defines Resilient Packet Ring MAC.	First draft for ballot Q3 2002. Expected final standard mid 2003.
ANSI	T1.105	VCAT - Identical text to G.707/G.783 but with SONET terminology. GFP, LCAS - References G.7041/G.7042.	**Approved** 2001 version
ETSI	EN300 417-9-1	Defines VCAT as per G.707/G.783. No recent updates to include GFP/LCAS.	**Approved**

Table 4. *Next-generation SONET standards table*

	Point-to-point	RPR	Comments
Port aggregation		x	Point-to-point mapper: Just like any other TDM trib RPR: Provides the ability to share bandwidth and aggregate to a single head-end port
Layer 2 capable (logical customer separation, CoS, etc.)		x	Point-to-point mapper: Provide transparent transport of higher layer protocols. A front end Layer 2/L# device would be required for customer separation. RPR: Integrated Ethernet LAN
Subrate	x	x	Point-to-point mapper: Provided by WLAN bandwidth management and flow control RPR: Provided by token bucket rate limiting and flow control
Full rate over SONET	x		Point-to-point mapper: Support for STS-24c, nxSTS-1 (n=21) and nxSTS-3c (n=7) RPR: Provided by WAN load sharing and 2.4G RPR
Spatial Re-use		x	Point-to-point mapper: No bandwidth sharing RPR: Bandwidth shared between all stations on the WAN
Per port mappable	x		Point-to-point mapper: No bandwidth sharing RPR: All Ethernet ports are shared
Fibre channel	x		Point-to-point mapper: USES GFP-T and a new trib RPR: No support for PC

Table 5. *GFP (point-to-point) and RPR comparison*

Draft 2.0, code named “Darwin”, is the most recent version of the standard and the first to be circulated to a full working group ballot. The process will culminate with the publishing of the standard, which in the case of IEEE 802.17 and RPR is expected later in 2003.

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List of acronyms

AM	Amplitude Modulation
ATM	Asynchronous Transfer Mode
BLSR	Bi-directional Line Switched Ring
BW	Bandwidth
CAP	Control Access Protocol
CAPEX	Capital Expenditure
CBR	Constant Bit Rate
CMTS	Cable Modem Termination System
CO	Central Office
CRM	Customer Relations Management
DHUB	Distribution Hub
DOCSIS	Data Over Cable System Interface Specification
DPT	Dynamic Packet Transport
DVC	Digital Video Compression
DVB-ASI	Digital Video Broadcast Asynchronous Serial Interface
DWDM	Dense Wavelength Division Multiplexing
ETSI	European Telecommunications Standardization Institute
FR	Frame Relay
GbE	Gigabit Ethernet
Gbps	Gigabits per second
GFP	Generic Framing Procedure
HDT	Host Digital Terminal
HE	Head-end
HFC	Hybrid Fiber Coaxial
IEEE	Institute of Electrical and Electronic Engineers
INM	Integrated Network Management
ISP	Internet Service Provider
IPPV	Impulse Pay Per View
IP	Internet Protocol
JIT	Just in Time
LAN	Local Area Network
MAN	Metropolitan Area Network
Mbps	Mega bits per second
MPLS	Multi Protocol Label Switching
MSO	Multiple System Operator
NE	Network Element
NEBS	Network Equipment Building System
NSG	Network Services Gateway Ethernet to QAM Converter made by Harmonic Inc.
OAM+P	Operations, Administration, Maintenance, and Provisioning
OC	Optical Carrier
PC	Personal Computer
PCM	Pulse Code Modulation
POS	Packet over SONET
PPV	Pay Per View
PSTN	Public Switched Telephone Network
QAM	Quadrature Amplitude Modulation
QOS	Quality of Service
RF	Radio Frequency
RPD	Return Plant Demodulator
RPR	Resilient Packet Ring
SAN	Storage Area Network
SDH	Synchronous Digital Hierarchy
SLA	Service Level Agreement
SNMP	Simple Network Management Protocol
SOHO	Small Office, Home Office
SONET	Synchronous Optical Network
SRP	Spatial Re-use Protocol
STB	Set Top Box
STM	Synchronous Transfer Mode
STS	Synchronous Transport Signal
TD	Transparent Domain
TDI	Transparent Domain Identifier
TDM	Time Division Multiplexing
UNI	User to Network Interface
VLAN	Virtual Local Area Network
VOD	Video on Demand
VoIP	Voice Over Internet Protocol
VPN	Virtual Private Network
WAN	Wide Area Network

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